THERMAL MANAGEMENT CHARACTERISTICS FOR A FUEL CELL HYBRID VEHICLE UNDER REALISTIC DRIVING DEMANDS

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Abstract

The performance of a fuel cell vehicle is affected by ambient conditions. In this study, the impact of high altitude and ambient temperature on fuel cell system performance was studied. It was determined that the fuel consumption increases with increasing elevation. The impact is more apparent in high power drive cycles. As the ambient temperature increases, it is more difficult for the radiator to reject heat to the ambient. This in turn makes it more difficult to control the fuel cell stack operating temperature.

Introduction

Ambient operating conditions including temperature and altitude have a considerable impact on fuel cell hybrid vehicle performance. The compressor and auxiliary system loads will increase to compensate for the effects of lower ambient pressures encountered at higher elevation on system performance. Ambient temperature affects the ability of the system to reject heat and will factor into sizing of thermal management components. This paper builds upon the parametric analysis performed in a previous study [1], and focuses on the impact of off-cycle operational conditions on fuel cell system heat loads and overall vehicle performance.

Approach

The ambient temperature and pressure, here used as a function of elevation, were varied during different drive cycles in order to investigate their impact on the fuel cell system thermal management and vehicle performance. The following drive cycles were studied:

- UDDS – Urban Dynamometer Driving Schedule, represents typical urban driving, part of U.S. EPA Federal Test Procedure
- HWFET- high speed, moderate acceleration rate driving profile
- US06 – high-speed, high-acceleration-rate driving profile to be included in U.S. EPA Supplemental Federal Test Procedure (SFTP)
- NREL2Vail - a logged route from the National Renewable Energy Laboratory (NREL), Golden, Colorado, to Vail, Colorado.

The UDDS, HWFET and US06 cycles have also been used for simulations at high constant altitude. All drive cycle results, except for the NREL2Vail route, are presented as “state of charge (SOC) balanced”, meaning that the difference between the battery pack SOC at the end of the cycle is not significantly different than the battery pack SOC at the beginning of the cycle. This is necessary to provide comparable fuel economy results.

Vehicle assumptions and fuel cell system characteristics

A compact fuel cell hybrid vehicle was defined in ADVISOR™, the National Renewable Energy Laboratory’s vehicle simulation software [2, 3]. Table 1 shows the vehicle assumptions and summarizes the hybrid component characteristics. The fuel cell system is assumed to remain on at all times during the drive cycle unless the ignition key is turned off. The battery pack in this system is used for power-assist and regenerative braking energy recovery during drive cycles.

The powertrain model used in the hybrid vehicle was a direct hydrogen PEM fuel cell system model developed by Virginia Tech. The fuel cell system model takes both thermal and water management into account. Figure 1 shows a schematic of the model. More details about the model can be found in [2].

Table 1: Vehicle and powertrain component characteristics

Vehicle	Description
FC hybrid vehicle mass	1364 kg (with power-train)
Powertrain	**Description**
FC system	50 kWe (pressurized)
Motor/ controller	70 kW AC induction motor/inverter
Energy storage system	6 Ah Li-ion battery pack

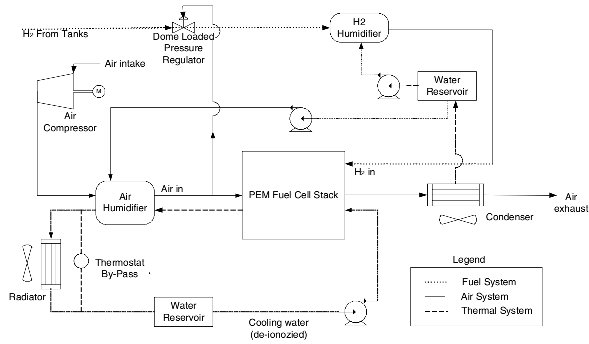

Figure 1: Schematic of the fuel cell system model.

Results and discussion

The vehicle fuel consumption is affected by the drive cycle elevation as shown in Figure2. The fuel consumption increases with increasing altitude. The impact is greatest on high power drive cycles like the US06. The operating pressure of the fuel cell system was assumed to increase linearly with increasing power demand. The ambient pressure is also decreasing with increasing altitude. Therefore, the air compressor must work even harder to provide the desired pressure ratio. The impact of the air compressor parasitic load is compounded on aggressive driving profiles at altitude. Consequently, a 50% increase in fuel consumption is observed on the more aggressive US06 cycle when we move from 0m elevation up to 3000 m. In comparison, the fuel consumption penalty associated with the same change on more moderate cycles, like the HWFET, and the UDDS cycles as shown in Figure 2, is approximately 20% and 30% respectively.

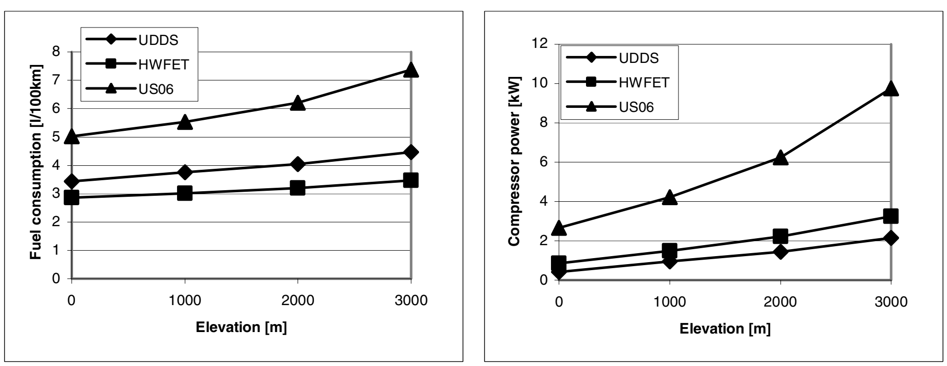

Figure 2. Impact of altitude on fuel consumption and parasitic load over drive cycles.

In addition to altitude, the fuel cell vehicle performance is affected by ambient temperature. Figure 3 provides an example of the effect of ambient temperature. As the ambient temperature increases, it becomes more difficult for the radiator to reject heat to the ambient environment. As a result, it becomes more difficult to control the fuel cell stack operating temperature. In Figure 3, we see that the heat rejected by the radiator is less for higher ambient conditions. In turn, the stack coolant temperature continues to rise as shown in the top portion of Figure 3. In these analyses, the coolant flow rate is calculated to maintain ~5 degree temperature difference across the stack and both fan control and vehicle speed are taken into account in the radiator heat transfer correlation. Under high ambient temperature conditions it maybe necessary to increase the coolant flow rate to compensate for the smaller temperature difference.

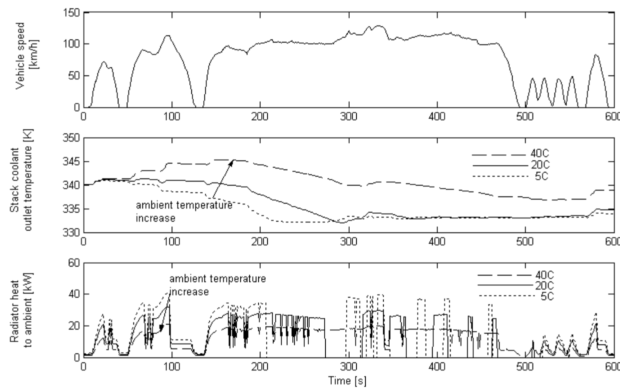

Figure 3. Effects of ambient temperature over the US06 drive cycle. Elevation= 0m. Fuel cell system initial temperature=340 K.

Elevation and vehicle speed data were logged for the route between the National Renewable Energy Laboratory (NREL) in Golden, Colorado and Vail, Colorado. The route is primarily highway driving at a speed 95 km/h and includes two mountain passes over 3000m as shown in Figure 4. The corresponding change in ambient pressure with elevation is also provided.

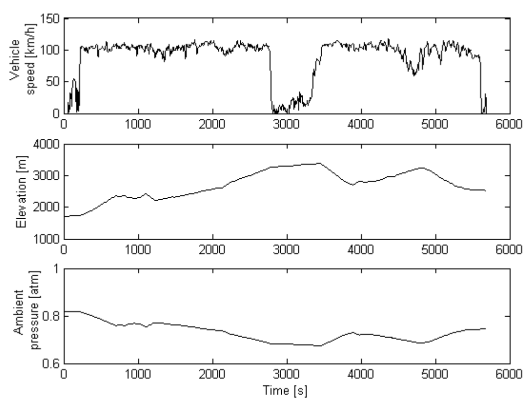

Figure 4. Driving profile for the logged route between Golden, Colorado and Vail, Colorado.

The operating characteristics of the fuel cell system during the NREL to Vail route are shown in Figure 5. Again the stack coolant temperature is controlled with the radiator. Initially, the radiator is by-passed in order to raise the fuel cell stack temperature and system efficiency quickly. Once the system reaches normal operating temperature, the radiator fan and bypass valve are used along with the vehicle speed to keep the system between 333 and 348 K. Forced convection due to the vehicle speed and the radiator fan (primarily under low speed operation) is considered.

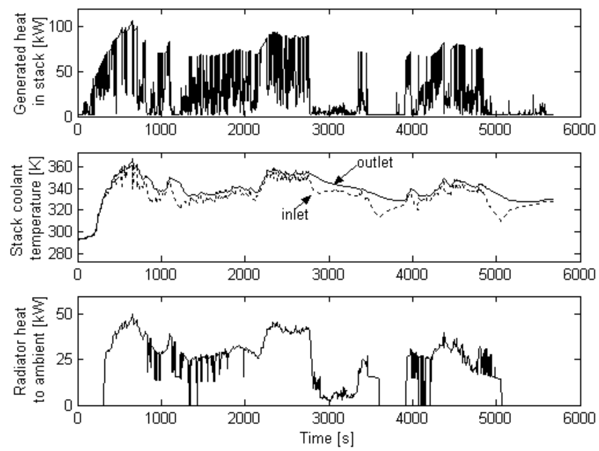

Figure 5. Thermal characteristics of the fuel cell system operation during mountainous driving.

Conclusions

The vehicle performance is affected by ambient conditions such as altitude and ambient temperature. We found the fuel consumption increases with altitude and the magnitude of increase is dependent on drive cycle characteristics. In this study, the change ranges from 20 to 50% for change in elevation from sea level up to 3000m. The heat rejection of the radiator is limited with increasing ambient temperatures. Controlling the fuel cell stack operating temperature will be more difficult under higher ambient temperatures.

References

[1] Kristina Haraldsson, Tony Markel, Keith Wipke. *An Analysis of Water Management for a PEM Fuel Cell System in Automotive Drive Cycles*. Proceedings, ASME Fuel Cell Science, Engineering and Technology, Rochester, New York, 2003.

[2] Tony Markel, Keith Wipke, Doug Nelson, *Vehicle System Impacts of Fuel Cell System Power Response Capability*, SAE Publication 2002-01-1959, 2002.

[3] Kristina Haraldsson, and Keith Wipke, *Evaluating PEM Fuel Cell System Models*, in Proceedings, #246, 202nd Electrochemical Society Meeting, Salt Lake City, UT, 2002.